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Intelligent unified power quality conditioner based photovoltaic to improve grid reliability and mitigate power quality issues

Problem. *Electrical distribution networks are plagued by power quality problems, which have a negative impact on sensitive electrical loads. These problems include reactive current, low power factor on the load side, and voltage harmonics, voltage sags and voltage swells on the grid voltage side. To address these issues, a unified power quality conditioner (UPQC) that combines shunt and series compensators is suggested. The* ***goal*** *of the work is to implement a UPQC integrated with a photovoltaic (PV) system to mitigate power quality problems in the power system, and boosting the grid supply through power injection from the PV system.* ***Methodology.*** *One of the less complex and effective ways to improve the grid's voltage quality is by using the unit vector template generation (UVTG) strategy as the composition technique (UPQC-P) through the UPQC series compensator. The synchronous reference frame (SRF) strategy through the UPQC shunt compensator to improve the current quality on the load side is used. To further optimize the SRF strategy, it is used the snake optimization (SO) to find the optimal values for the PI controller's parameters.* ***Results.*** *The UPQC-PV is used to mitigation the power quality issues in the grid and loads by UVTG and SRF techniques in series and shunt compensators, respectively.* ***Scientific novelty****. The composition technique (UPQC-P) through a series compensator and uses the SO for tuning the PI controller in the shunt compensator.* ***Practical value.*** *This study reduces the total harmonic distortion (THD) in the load voltage to 0.57 %, while the THD in the grid voltage remains at 10 %. It restores the load voltage to its reference value of 230 V during voltage sags (down to 161 V) and swells (up to 300 V) in the grid. Additionally, it mitigates the low power factor on the load side (0.707 lagging) to achieve a unity power factor in grid current, balances the unbalanced load current to a balanced grid current, and enhances grid stability by injecting power from the PV system into the grid.* References 33, table 3, figures 7.

Key words: **power quality, unified power quality conditioner, unit vector template generation, synchronous reference frame strategy, photovoltaic system.**

Проблема*. Розподільні електромережі страждають від проблем якості електроенергії, які негативно впливають на чутливі електричні навантаження. Ці проблеми включають реактивний струм, низький коефіцієнт потужності на стороні навантаження, а також гармоніки напруги, зниження та стрибки напруги на стороні напруги мережі. Для вирішення цих проблем пропонується єдиний стабілізатор якості електроенергії (UPQC), який поєднує шунтуючі та послідовні компенсатори.* ***Метою*** *роботи є впровадження UPQC, інтегрованого з фотоелектричною (PV) системою, для зменшення проблем якості електроенергії в енергосистемі та підвищення потужності мережі шляхом подачі енергії в мережу.* ***Методика****. Одним з менш складних та ефективних способів покращення якості напруги мережі є використання стратегії генерації шаблонів одиничних векторів (UVTG) як методу композиції (UPQC-P) за допомогою послідовного компенсатора UPQC. Використовується стратегія синхронної системи відліку (SRF) через компенсатор шунту UPQC для покращення якості струму на стороні навантаження. Для подальшої оптимізації стратегії SRF використовується оптимізацію типу «змійка» (SO), щоб знайти оптимальні значення параметрів ПІ-регулятора.* ***Результати****. Метод UPQC-PV використовується для зменшення проблем із якістю електроенергії в мережі та навантаженнях за допомогою методів UVTG та SRF у послідовних та шунтуючих компенсаторах відповідно.* ***Наукова новизна****. Метод композиції (UPQC-P) використовує послідовний компенсатор та використовує SO для налаштування ПІ-регулятора в шунтуючому компенсаторі.* ***Практична значимість*** *полягає у зменшенні загального коефіцієнта гармонійних спотворень (THD) у напрузі навантаження до 0,57 %, тоді як THD у напрузі мережі залишається на рівні 10 %, а також відновлення напруги навантаження до опорного значення 230 В під час зменшення (до 161 В) та зростань (до 300 В) напруги в мережі. Крім того, отримано зменшення низького коефіцієнта потужності на стороні навантаження (затримка 0,707) для досягнення одиничного коефіцієнта потужності в струмі мережі, вирівняння незбалансованого струму навантаження до збалансованого струму мережі та підвищення стабільності мережі шляхом введення енергії з PV системи в мережу.* Бібл. 33, табл. 3, рис. 7.

Ключові слова: **якість електроенергії, уніфікований стабілізатор якості електроенергії, генерація шаблону одиничного вектора, стратегія синхронної системи відліку, фотоелектрична система.**

Introduction. The primary goals of electrical distribution networks are to ensure a constant power flow from the grid and to provide consumers with a pure sinusoidal voltage and frequency [1]. Distribution networks have recently faced challenges with power quality, including imbalanced loads, harmonic load currents, and high reactive power consumption [2]. Additionally, these devices do not protect the customer's load end from surges, dips, fluctuations, imbalances, or voltage swells in the grid. To prevent power quality defects from activating their protective mechanisms, critical loads including medical devices and financial facilities that use uninterruptible power supplies require constant, sinusoidal, balanced voltages with a steady frequency and magnitude [3, 4]. This results in a financial loss due to decreased efficiency, time, quality, and consumer satisfaction [5]. The best solution for addressing voltage and current quality issues for sensitive loads seems to be a sort of robust, reliable device called a unified power quality conditioner (UPQC). One answer to many power quality issues is the UPQC, which combines shunt and series compensators [6]. The shunt component of the UPQC, connected in parallel to the load, delivers reactive power compensation, load unbalancing, and harmonic mitigation resulting from nonlinear loads. The series component of the UPQC, which is interconnected between the grid and the load, addresses issues related to sag, swell, variations, imbalance, and harmonic voltage in the grid [7].

The goal of the work is to implement a UPQC integrated with a photovoltaic (PV) system to mitigate power quality problems in the power system, and boosting the grid supply through power injection from the PV system.

Review of the literature. In 1998, Fujita and Akagi implemented the earliest use of UPQC utilizing a series active power filter (APF) and a shunt APF with an integrated DC link [8]. Subsequent years saw additional researchers examining the UPQC and developing various topologies, mathematical models, and control methodologies for it. The research article employs a single-phase UPQC to mitigate power quality challenges in grid-connected solar systems, including voltage sags and swells, as well as linear and nonlinear loads. The system employs a unit vector template generation (UVTG) control algorithm in both the shunt and series inverters of the UPQC, utilizing a phase-locked loop (PLL) and the composition technique (UPQC-P) to enhance voltage and current quality [9]. The article presents an effective sizing methodology for a solar PV based on UPQC with distributed generation (UPQC-DG), which mitigates power quality concerns such as voltage sags and swells and reactive nonlinear loads while decreasing the supply current across all operational conditions through the PV system. The method employs an enhanced power angle control (PAC) technique utilizing nonlinear programming methods to equilibrate the reactive power load between series and shunt converters, the composition technique (UPQC-S) in the series converter, and the synchronous reference frame (SRF) theory in the shunt converter [10]. The study suggests improving the solar PV-based UPQC-DG to address power quality challenges, such as voltage sags and swells, reactive nonlinear loads, and to offer reactive power assistance to the grid. The system regulates load reactive electricity and exports it to the grid systematically. The control methodology integrates the composition approach (UPQC-S) within the series converter alongside PAC and SRF theory in the shunt converter. A PI controller manages reactive power flow, whereas the PAC approach allocates the reactive power load between series and shunt APFs to diminish the total rating [11]. This research examines the UPQC-PV's role in delivering regulated electricity and preserving power quality. The system utilises an adaptive notch filter-based instantaneous symmetrical component controller for series compensation of voltage sags and swells, the composition technique (UPQC-P), and a moving average filter employing an adaptive hyperbolic tangent function controller for shunt compensation to regulate current supply in case of nonlinear loads. Simulations validate the system's effectiveness, showing a significant reduction in total harmonic distortion (THD) from 33.45 % to 2.45 % [12]. This article describes a system that includes a standalone hydro turbine-driven permanent magnet synchronous generator that supplies sensitive and nonlinear loads through a UPQC-based energy storage system. The UPQC mitigates harmonic voltage supply and current quality problems, including reactive power compensation and harmonic removal, while modifying the load, incorporating series (the composition technique UPQC-P) and shunt compensators [13]. This research introduces a unified framework for adaptive and variable phase angle control in single-phase UPQC, employing the practical optimized-Volt-Ampere (VA) loading operational strategy and the universal flexible control method (the composition technique UPQC-S). The proposed approach can systematically and iteratively determine the optimal phase angle across different power ratings and various grid disturbances. This technique employs a gradual alteration of the phase angle to mitigate its impact on sensitive loads. A comparison with the UPQC-P approach revealed a reduction in VA loading with the proposed technique [14]. This paper proposes an operation scheme for the UPQC under VA capacity constraints using hierarchical optimization. The approach contains 3 optimization objectives:

1) reducing load voltage deviation;
2) improving the power factor of the power grid;
3) minimizing the total apparent power of the UPQC (the compositional approach UPQC-S) [15].

The research seeks to improve power quality in grid-connected renewable energy systems (PV-wind) with nonlinear loads. The study examines the deployment of the UPQC, which consists of a series of components utilizing the UVTG strategy and a shunt component employing the SRF algorithm. APFs are linked by a DC connection to alleviate harmonic distortions and voltage imbalances (sag and swell) referred to as the composition technique (UPQC-P) [16]. This article defines the Volterra expansion filter using the least mean square (LMS) and least mean square/fourth (LMS/F) control algorithms on UPQC. Additionally, a non dominated sorting genetic algorithm-II optimization method is employed to determine the PI controller gains within the Volterra LMS/F control algorithms. Voltage source disturbances are (sag, harmonic and unbalance), and 3-phase nonlinear loads. A zigzag transformer is applied on the load side to mitigate neutral current when the load configuration is a 3-phase system. Given that the UPQC circuit configuration is 3-phase 3-wire, the composition technique (UPQC-P) [17]. This paper discusses the treatment of power quality issues, including sag, swell, and nonlinear loads, through a UPQC-PV using the PAC strategy in the series converter, The composition technique (UPQC-S) and a shunt converter utilizing SRF strategy, alongside the optimization of PI controller parameters in the shunt converter via particle swarm optimization to enhance the stability and performance of the DC link voltage under varying operational conditions [18]. The study introduces a method that reduces demand on load voltage sensors and source current sensors in managing the series and parallel components of the UPQC device. The line voltage for 2 phases of the load was measured, and the 3rd phase was inferred, along with the source current. PV system was integrated with the UPQC device to enhance power quality and increase the reliability of the source by reducing the active power delivered to the load. The study examines system disturbances, including harmonics, asymmetrical voltage sags and swells (unbalance), nonlinear loads, and unbalanced loads by removing one of the load phases. The primary drawback of this paper is that, in instances of voltage imbalance in one phase, not only is the voltage of the unbalanced phase compensated, but the voltages of the remaining healthy phases are also compensated. Additionally, algorithms for maximizing power from the PV system are not employed, as it is directly connected to the UPQC device. The composition technique (UPQC-P) and 3-phase 3-wire type UPQC [19]. This paper proposes a method for implementing a variable leaky LMS adaptive compensation strategy as a replacement to a low-pass filter for tracking the fundamental component of current and voltage signals in the control of shunt and series inverters of the UPQC-PV, addressing power quality issues such as voltage sags, swells, and both balanced and unbalanced non-linear loads. The limitation of this technique depends on the estimation method employed. The approach is complex and challenging to calculate its optimal values. Furthermore, strategies designed to optimize power extraction from the solar system are not utilized, as it is directly linked to the UPQC device. The composition method (UPQC-P) and the 3-phase 3-wire type UPQC [20].

UPQC system configuration. Series and shunt compensators are integrated in UPQC-PV (Fig. 1). The 3-phase, 4-wire UPQC's power circuit consists of 2 voltage source inverters (VSIs) connected by a shared DC link capacitor at the DC bus. At its core, it consists [21, 22]:

1) The series compensator, situated between the grid supply and the load, serves as both a dynamic voltage restorer and a series compensator within the UPQC. This compensator work is to return the load voltage to its reference value while keeping the voltage at the consumer load unaffected by issues with the grid voltage.

2) The shunt compensators, also known as distribution compensators (DSTATCOMs) in the UPQC framework, are inverters that are linked in parallel with the load. Their purpose is to improve the current quality and reduce the unbalanced load current.

3) A UPQC consists of several passive components. These components include an AC coupling inductor to connect the 2 VSIs to the grid, a DC-link capacitor (also referred to as a DC bus capacitor) to supply DC voltage to the VSIs, and LC filters to minimize switching ripples in the outputs of the shunt and series compensators.

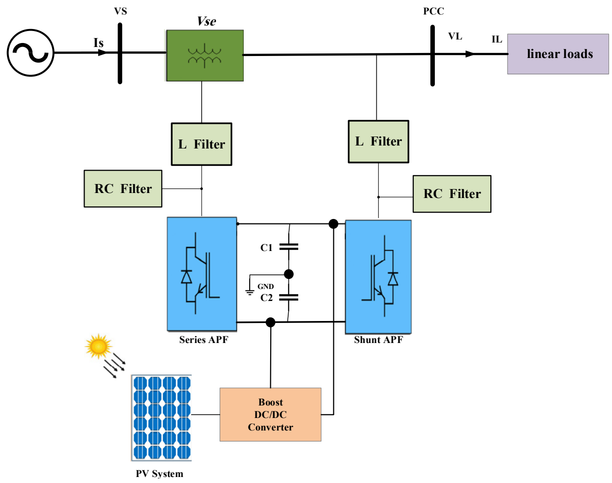

Fig. 1. Configuration of the UPQC-PV

Control technique for UPQC. Control strategy of series compensator. This section ensures that the load voltage meets the necessary values and is free of power quality issues by addressing voltage quality concerns related to sag, swell, and harmonics in the source voltage. An approach called UVTG is put into action by the control circuit. A PLL is used to produce the phase angle (ωt) at the source voltage's fundamental frequency. It then generates 3-phase signals at the same frequency, free of power quality concerns, and compares them to the load voltage. Afterwards, pulse width modulation (PWM) is used to generate the series inverter circuit's gate signals [23]. The UPQC series compensator (Fig. 2) is responsible for delivering load voltages free of distortion.

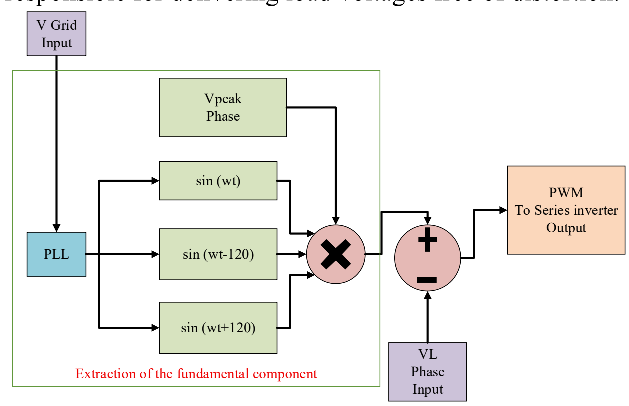

Fig. 2. The control circuit of series compensator in UPQC-based UVTG technique

Control strategy of the shunt compensator (DSTATCOM). This section addresses quality issues in the current source, specifically concerning low power factor and reactive power as well as imbalances resulting from uneven loads on the load side. The system regulates the DC link voltage via a PI controller [24], with its parameters optimized using the snake optimization (SO) algorithm to achieve optimal performance in the source current. Figure 3, which depicts the SRF theory, shows how to generate the reference current signal using the SRF method, moreover a *dq*0 frame is used to alter the load currents from an *abc* frame. After that, any harmonics in the I_d component are filtered out using the low pass filter (LPF). After that, it becomes the I_d fundamental, and then, to get the harmonic numbers, we subtract this component from the initial I_d value. After that, the PI controller's output signal is integrated with the value [25]. To generate the 3-phase source's fundamental frequency, use a PLL. By contrasting the reference currents with the 3-phase shunt compensator's output current, this technique uses hysteresis to produce gate signals for the shunt compensator [26].

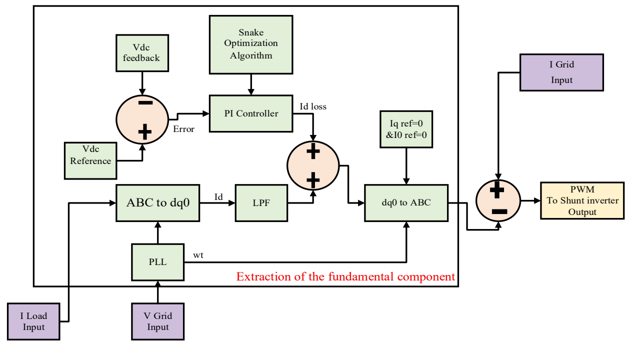

Fig. 3. The control circuit of shunt compensator in UPQC-based SRF technique

PV system control. To optimize solar power systems, the perturb and observe (P&O) algorithm makes incremental changes to the system and then monitors the impact of those changes on the system's power production. To find the best perturbation direction for the highest power, it compares the current and past power levels. To maximize the benefits of a solar system, boost converters are utilized by increasing the output voltage of the PV panel to the level necessary for the UPQC to operate with the minimal number of PV panels [27]. Using the maximum power point tracking approach, which is based on the P&O algorithm, is a prominent way to enhance the efficiency of UPQC. The P-V characteristics of PV panels as they are exposed to solar radiation are shown in Fig. 4.

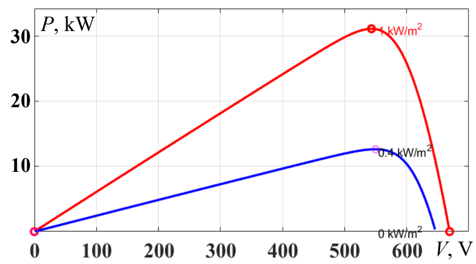

Fig. 4. P-V characteristics of PV panels

Figure 5 shows the flowchart of the P&O algorithm to find the maximum power under the influence of solar radiation and heat directed at the PV panels.

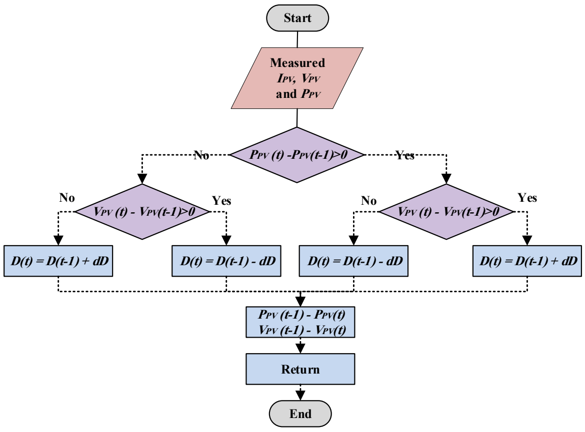

Fig. 5. The flowchart of P&O algorithm

Snake optimization. Snake reproductive behavior is affected by variables such as temperature and food accessibility. Mating often transpires in late spring and early summer when temperatures are moderate. When food is plentiful, male snakes vie for the attention of females. The female determines the suitability of a partner, and upon copulation, she deposits her eggs in a nest or burrow and departs after hatching [28]. The SO method is derived from the reproductive behavior of snakes. It functions in 2 stages: exploration and exploitation. In the absence of food and freezing temperatures during exploration, the snake seeks sustenance. In exploitation, the serpent prioritizes efficiency, adjusting according to food supply and temperature. When food is accessible and temperatures are elevated, the snake consumes it. Mating occurs under simultaneous conditions of food and cold, characterized by 2 modes: a competitive mode, in which males vie for females, and a mating mode, wherein pairs copulate depending on food availability. Upon mating, the female may deposit eggs that subsequently hatch into baby snakes [29].The mathematical model and technique are elucidated in depth in the following sections:

1) *Initialization* [30–32]: before beginning the optimization process, SO, like other metheuristic algorithms, creates a uniformly distributed, randomly generated population. The following equation can be used to find the initial population:

$$x_i = x_{\min} + r \cdot (x_{\max} - x_{\min}), \quad (1)$$

where x_i is the position of i^{th} individual; r is the random number between 0 and 1; $x_{\max}$, $x_{\min}$ are the lower and upper bounds of the problem respectively.

Assuming there are n_m males and n_f females in the swarm, after initialization the swarm will be divided into 2 equal groups. In order to assess each group, we can define food and temperature using (2) for temperature *Temp* and (3) – for food quantity Q:

$$Temp = \exp(-t / T); \quad (2)$$

$$Q = c_1 \cdot \exp[(t - T) / T]; \quad (3)$$

where t, T are the current and maximum iteration times, respectively; c_1 is the constant equal to 0.5.

2) *Exploration phase* (no food) [30–32]: if the value of Q is less than the threshold (where the threshold is 0.25), the snakes will update their position relative to any randomly chosen position in their search for food. To model the exploration phase, the following equation is used:

$$x_{i,m}(t+1) = x_{rand,m}(t) \pm c_2 \cdot a_m \cdot [(x_{\max} - x_{\min}) \cdot rand - x_{\min}]; \quad (4)$$

$$x_{i,f}(t+1) = x_{rand,f}(t) \pm c_2 \cdot a_f \cdot [(x_{\max} - x_{\min}) \cdot rand - x_{\min}]; \quad (5)$$

where a_m, a_f are the individuals' respective food-finding capacities; *rand* is the random number between 0 and 1; c_2 is the constant equal to 0.05 [30–32].

3) *Exploitation phase* (food exists) [30–32]: the food is available if the quantity exceeds the threshold value 0.6. After that, the snakes will start to feel the temperature. Only when the temperature drops below 0.6 will the snakes start eating what's already there. The process is illustrated below:

$$x_{i,j}(t+1) = x_{food} \pm c_3 \cdot Temp \cdot rand \cdot [x_{food} - x_{i,j}(t)], \quad (6)$$

where $x_{i,j}$ is the position of individual (male or female); x_{food} is the position of the best individuals; c_3 is the constant equal to 2.

SO was used in this work to find the best parameters for PI controller [33] in UPQC by the objective function by integral error.

$$IAE = \int_0^t |e(t)| \mathrm{d}t \,. \quad (7)$$

Table 1 explains the parameters of SO algorithm.

Table 1

The parameters of SO algorithm

Parameters	Values
Number of variables	K_P, K_I
Minimum desirable	[0, 0]
Maximum desirable	[50, 50]
Population size and iteration number	20, 50

Results and simulation. A right-shunt UPQC configuration with 3 phases and 4 wires was modeled in the MATLAB/Simulink program. The power system and UPQC parameters are listed in Table 2.

Table 2

The power system parameters

Parameters	Value
Grid voltage V, V	400
Grid frequency f, Hz	50
3 phase balance load P, kW, Q, kVAr	20 20
3 phase unbalance load P_{abc}, kW, Q_{abc}, kVAr	6, 7, 8 6, 7, 8
PI parameter for balance load K_P, K_I	0.6925 12.2467
PI parameter for unbalance load K_P, K_I	0.6234 22
DC link voltage V_{dc}, V	800
DC link capacitor C_1, mF, C_2, mF	4 4
Shunt inductance L_{sh}, mH	3
Shunt filter capacitance C_{sh}, µF, filter resistance R, Ω	600 6
Series inductance L_{se}, mH	30
Series filter capacitance C_{se}, µF, filter resistance R, Ω	150 6
Rated power P, kW	29.6
Open-circuit voltage V_{oc}, V	47.8
Short-circuit current I_{sc}, A	10.17
Voltage at maximum power V_{mp}, V	38.8
Current at maximum power I_{mp}, A	9.54
Number of cells in parallel	6
Number of cells in series	14
Boost converter inductance L, mH	0.35
Boost converter capacitance C, µF	220

The line-to-line voltage of the grid is 400 V, so the phase voltage is 230 V. The instances of mitigating power quality issues through the UPQC are categorized as follows.

1) the voltage quality issues in the grid (sag, swell and harmonics). Figure 6 shows all cases of the power quality issues in grid voltage and load side.

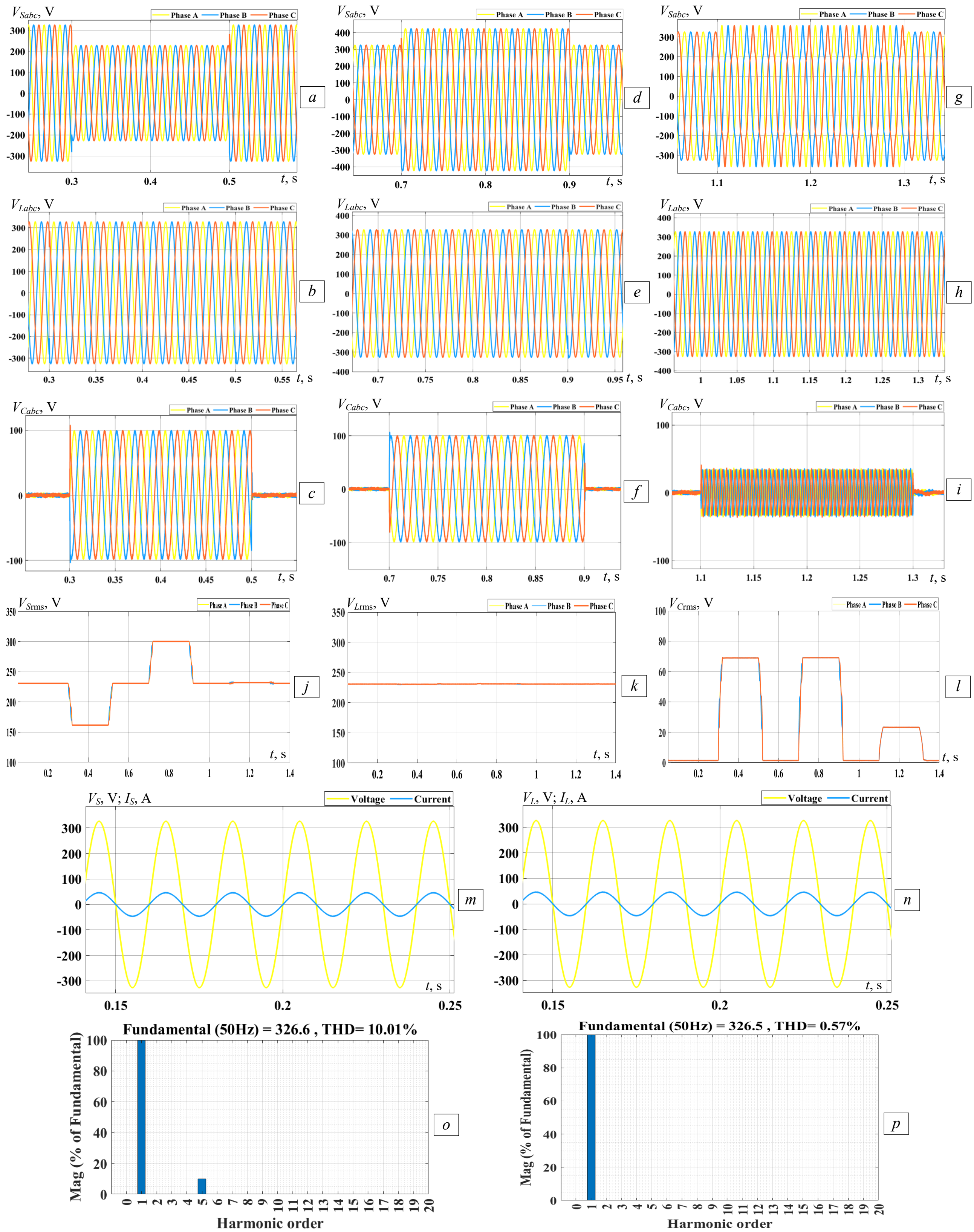

Fig. 6. All cases of the power quality issues in grid voltage and load side: *a* – sag grid voltage; *b* – voltage injected by series part of UPQC; *c* – load voltage; *d* – swell grid voltage; *e* – load voltage; *f* – voltage injected by series part of UPQC; *g* – harmonics grid voltage; *h* – load voltage; *i* – voltage injected by series part of UPQC; *j* – RMS grid voltage; *k* – RMS load voltage; *l* – RMS voltage injected by series part of UPQC; *m* – grid waveforms of voltage and current; *n* – load waveforms of voltage and current; *o* – THD of grid voltage; *p* – THD of load voltage after mitigation by UPQC

The UVTG technique in series UPQC to mitigate the voltage quality issues under voltage sag (30 % p.u) of the grid voltage between (0.3–0.5) s in Fig. 6,*a* and the phase RMS voltage grid is 161 V (Fig. 6,*j*), voltage swell (30 % p.u) of the grid voltage between (0.7–0.9) s in Fig. 6,*d* and the RMS phase voltage grid is 300 V (Fig. 6,*j*) and distorted grid voltage by harmonic 5th order (0.1 p.u of the fundamental grid voltage, zero degree) during (1.1–1.3) s in Fig. 6,*g*. The series part of UPQC works to solve the problems of the voltage source by injecting a voltage in series between the grid and load side so that when a sag occurs, it injects a voltage with the same percentage of the decrease but in phase with the grid voltage in Fig. 6,*c* so that the load voltage is constant and is not affected by the reduction of the grid voltage in Fig. 6,*b*. Similarly, when a swell in the grid voltage occurs, it injects a voltage in series with the same value as the swell but in the opposite phase of the grid voltage in Fig. 6,*f*. When a distortion occurs in the grid voltage, the UPQC works to inject a voltage that contains harmonics in the opposite phase of the harmonics present in the voltage grid in Fig. 6,*i*, resulting in a THD of 10 % in the grid voltage in Fig. 6,*o*. The THD in load voltage decreased after the injection process via the series part to 0.57 % in Fig. 6,*p*. Thus, the load voltage always remains constant in value from the reference value and a pure sinusoidal form, free of voltage problems in the source in Fig. 6,*b*,*e*,*h*. And a control mechanism utilizing the SRF *d-q* methodology in a shunt part of UPQC were employed to address current quality concerns. Balanced reactive load is 20 kVAr and power factor in load side is 0.707 in Fig. 6,*n* along with the control techniques employed for shunt part the SRF uses adjusted PI control parameters optimized by the SO algorithm to mitigation the reactive power in grid current the power factor unity for all phase in Fig. 6,*m*.

2) The current quality issues in the load (unbalance load and reactive power compensations). In this part explain the integration of a PV system enhances the functionality of the UPQC system by increasing reliability and reducing grid losses by Fig. 7.

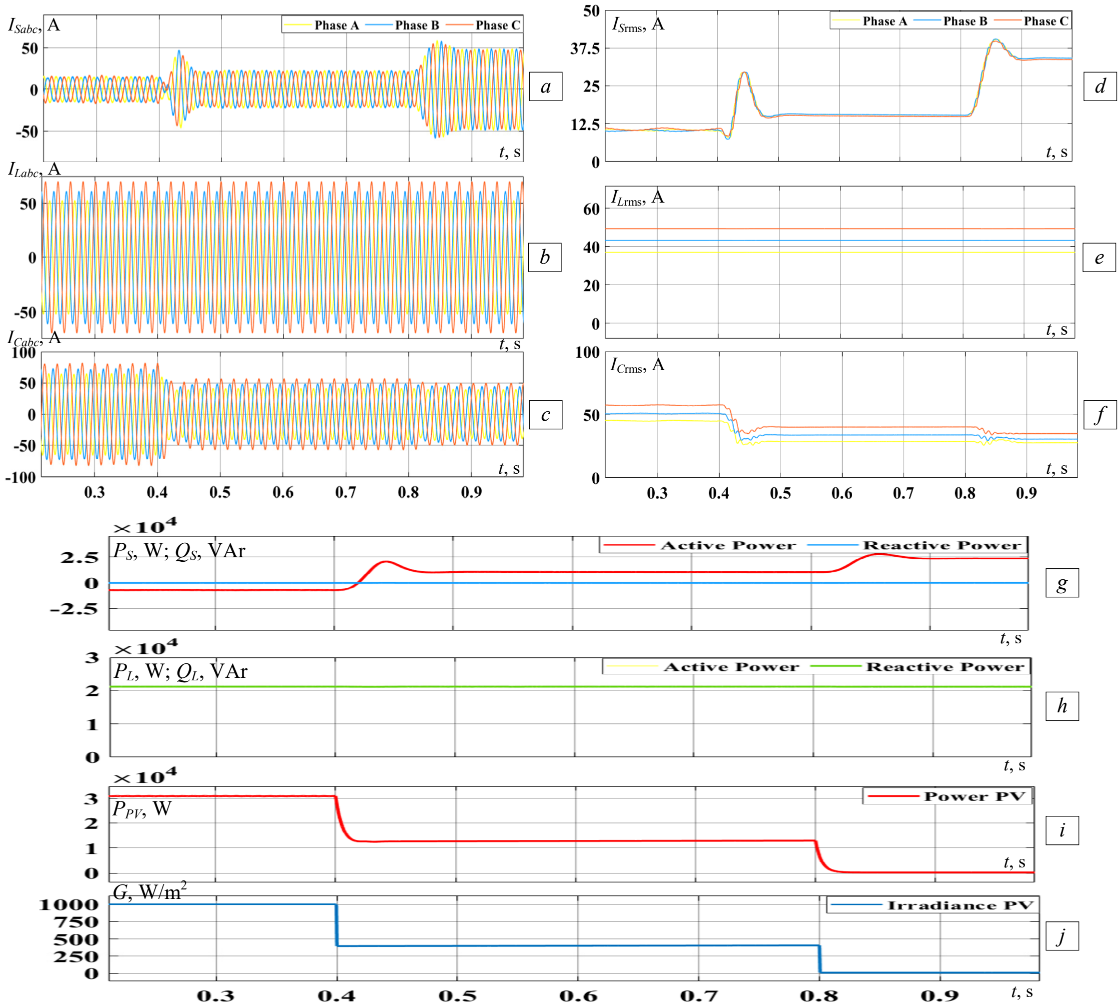

Fig. 7. All modes of the current quality issues in grid and load side: *a* – waveform grid current; *b* – waveform unbalance load current; *c* – current injected by shunt part of UPQC; *d* – RMS grid current; *e* – RMS of unbalance load current; *f* – RMS current injected by shunt part of UPQC; *g* – total active and reactive power of grid; *h* – total active and reactive power of load; *i* – total active PV power; *j* – solar radiation

The system operates in 3 distinct modes, depending on the ratio of the total active power of the load capacity to the active power of the PV generation capacity, based on the variation of the irradiance directed at the PV with the temperature factor on the cells at 25 °C, as follows.

Mode 1 (the active power of the PV system is greater than the active power of the load).

In this mode, the PV system generates an active power of 31 kW. In contrast, the total active power of the load is 21 kW. This occurs when the solar radiation intensity incident on the solar cells is 1000 W/m^2. Consequently, the solar cells provide electricity to meet the demand of the load, while the surplus energy is sent into the grid. Consequently, the grid is fortified with electrical power, thereby improving its stability.

Mode 2 (the active power of the PV system is less than the active power of the load).

In this mode, the PV system generates an active power of 12.6 kW. In contrast, the total active power of the load is 21 kW. This occurs when the solar radiation intensity incident on the solar cells is 400 W/m^2. Consequently, the solar cells provide part of the electricity to meet the load demand; in this mode, no surplus energy is sent to the grid.

Mode 3 (the PV system does not generate any active power). This occurs when the solar radiation intensity incident on the solar cells is 0 W/m^2. Therefore, the grid has to supply the total load demand.

In all modes, the imbalanced currents and reactive power are compensated on the grid side because the imbalanced load and power factors are 0.707 lagging in all phases. Table 3 explains the characteristics of connected the PV to UPQC to mitigation the current quality issues in load.

Table 3

All modes by integration of UPQC-PV

Parameters	Mode 1	Mode 2	Mode 3
Duration T, s	0–0.4	0.4–0.8	0.8–1
RMS grid current I_{abc}, A	10.2 10.6 10.62	15 15.38 15.4	33.4 33.85 33.88
RMS load current I_{abc}, A	37 43.2 49.4	37 43.2 49.4	37 43.2 49.4
Grid power P_{abc} kW, Q_{abc} kVAr	7.3, 0	10, 0	23.6 0
Load power P_{abc} kW, Q_{abc} kVAr	6, 7, 8 6, 7, 8	6, 7, 8 6, 7, 8	6, 7, 8 6, 7, 8
PV power P_{PV}, kW	31	12.6	0

Conclusions. Using UPQC integrated with a PV system to mitigate power quality problems in the power system and boost the grid supply through power injection from the PV system, the proposed work improves the electrical power quality supplied to sensitive electrical loads, which is a result of power quality problems in the grid system. Utilizing the UVTG strategy as the composition methodology (UPQC-P) through the UPQC series compensator is a straightforward and efficient method to enhance the voltage quality of the grid. To enhance the load side current quality, implement the SRF technique via the UPQC shunt compensator. In order to fine-tune the SRF strategy even further, we determine the best values for the parameters of the PI controller using SO. While the grid voltage maintains a THD of 10 %, this study brings the load voltage down to 0.57 %. Whenever the grid voltage drops below 161 V or rises above 300 V, it brings the load voltage back up to its reference value of 230 V. Achieving a unity power factor in grid current, balancing the imbalanced load current to a balanced grid current, and enhancing grid stability by injecting power from the PV system are all additional benefits. It also mitigates the low power factor on the load side (0.707 lagging).

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Conflict of interest. The authors declare that there is no conflict of interest.

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